NITROGEN FERTILIZATION OF SMOOTH BROMEGRASS

IN INTERIOR AND SOUTHCENTRAL ALASKA

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A

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Abstract

Although forage crops occupy the majority of agricultural land in Alaska, best fertilizer management practices to maximize forage yield and quality in Alaska are not well established. The objective of this study was to determine optimum time and rate of nitrogen (N) fertilizer applications to produce high yields of high quality forage in interior and Southcentral Alaska from smooth bromegrass (*Bromus inermus*). Nine N fertilization treatments, differing in rate and time of application, were applied at four sites. Forage samples were harvested twice per season in 1999 and 2000 to obtain yield and quality values. Nitrogen applied at 225 kg ha^{-1} produced greater yields than N applied at 125 kg ha^{-1}, but there were no significant differences between single and split applications. Yield and crude protein content of the control were significantly lower than plots receiving N treatment. Midseason application of N increased crude protein percentages in second cuts at most sites. Acid and neutral detergent fiber were not affected by N treatment. N fertilizer use appeared to be more efficient for split applications, but no significant differences were found. This study showed potential for the production of high yielding, good quality grass forages in Alaska under a variety of N fertilizer strategies.

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Introduction

Forage crops occupy about 76 percent of the developed agricultural land in Alaska (Benz et. al, 2006). Forages are the basis for dairy cattle diets, and their production requires minimal off-farm inputs, providing year-round soil cover that minimizes erosion and run-off. Although forage crops are grown successfully in both cool and warm season environments, management in cold environments such as Alaska may differ from more temperate regions further south.

One of the largest costs of milk production is commonly associated with feed. Management practices directly impact feed cost, yield, and quality. Distance from non-Alaskan feed sources and supplements are cause for greater management concerns in Alaska than most other states and Canadian provinces and affect costs.

Management systems for other states and Canadian provinces may not always suit Alaska. Differences in climate and location may alter specific components of the management system. The Alaskan environment is capable of producing high yielding, good quality, cool season forages that provide a major component in Alaskan dairy systems. Developing forage management systems specific to Alaska will enable Alaskan producers to better use this unique agricultural niche for dairy cattle.

Most cool season forage crops in Alaska are grasses. The most common agricultural grass in southcentral and interior Alaska is smooth bromegrass (*Bromus inermus*). Alaskan dairy systems depend on this grass for good quality forage. Management systems for high quality forage grasses are well defined in other states, but are limited in

Alaska. Specific fertilizer management systems tailored to the Alaskan environment for smooth bromegrass (*Bromus inermus*) are needed to produce higher yielding, better quality forage for dairy cattle diets and reduce management costs.

Literature Review

Agricultural investigations with forage began in Alaska along the southern coast in 1902 (Irwin, 1945). The chief Alaskan agricultural handicap has always been the short growing season, however, many forage plants have potential economic value for Alaskan producers (Capen and LeClerc, 1933). Native grasses have been more predominant in forage production than legumes in Alaska, but native grasses grow rapidly, mature early, and soon thereafter become unpalatable (Irwin, 1945). Capen and LeClerc (1933) found smooth bromegrass in Alaska (at similar growth stages) to be richer in sugar and a better forage crop than other introduced grasses and legumes. Smooth bromegrass is the dominant and most dependable introduced perennial grass adapted to practically all of the agricultural areas of Alaska (Laughlin, 1962; Irwin, 1945). Studies have shown smooth bromegrass to be more winter hardy than other common introduced grasses (Mitchell et al., 1987).

Harvested grasses and legumes, in the form of hay and silage, are the most common forages produced for livestock, especially in areas where winter conditions limit grazing (Horrocks and Vallentine, 1999). The management of forages on these lands is critical in meeting nutrient requirements for ruminant livestock (Bull, 1995). Producing and feeding high quality forages increases animal performance and reduces feeding costs (Bull, 1995; Horrocks and Vallentine, 1999).

Forage quality is often described in terms of nutritive value and intake potential (Marten, 1985; Scheaffer et al., 1998). Nutritive value is the chemical composition and digestibility of a forage: the carbohydrates, lipids, and proteins (including non-protein nitrogen) that provide most of the energy to the animal (Sollenberger and Cherney, 1995; Buxton and Mertens, 1995). The best single chemical indicator of intake potential is the cell-wall concentration measured by the Van Soest neutral-detergent fiber (NDF) fraction (Van Soest and Pidgen, 1980; Waldo, 1985). NDF is approximately equal to cell-wall concentration and a positive correlation between NDF and forage yield is a biological necessity as increased growth requires more structure (Casler, 2005). Laboratory analyses of forages determine the nutritional value to aid in management decisions and the formulation of rations for livestock (Sollenberger and Cherney, 1995).

Forage quality is best defined in terms of production per animal, however, measuring forage quality using animal performance trials is costly and time consuming. In response to these limitations, researchers have developed laboratory procedures to define forage quality. Effective laboratory methods of evaluating forages must be precise, economical, simple, rapid, and accepted by both the scientific community and the practitioner (Barnes, 1981). The primary standard for chemical evaluation of forages in the United States is the Van Soest system of fiber analysis. This system partitions forage carbohydrates into fractions based on nutritional availability (Marten, 1981). The Van Soest sequential fiber method measures cell-wall content of the fiber and partitions it into neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin. Neutral detergent fiber represents total cell wall content. The difference between NDF and ADF represents the hemicellulose portion, and the last step of the sequential fiber method represents the lignified material. When analyzing multiple samples, the Van Soest method can be slow and cumbersome. A relatively new procedure, near infrared reflectance spectroscopy (NIRS) is rapid (requiring less than one minute per sample analysis) and can measure multiple constituents from the measured spectra when calibrated against the Van Soest method and other chemical analyses (Shenk and Westerhaus, 1995).

High quality forages contain more digestible carbohydrate fractions, more crude protein (CP), and less cell wall material than low quality forages. Starch, sugar, and pectin make up the highly digestible carbohydrate fraction in feeds (Linn et al., 1996). The predominant chemical characteristic of forages that often determines the availability and amount of the digestible carbohydrate fraction is the forage cell wall content (Cheeke, 1991). The higher the percentage of forage cell wall, the lower the percentage of digestible carbohydrate; however, the ruminant animal needs the forage cell wall components to provide the rumen with fiber for normal rumen function and health (Van Soest et al., 1994; Buxton and Mertens, 1995; Schingoethe, 1988). The fiber of the cell wall stimulates the cardial region of the reticulum to induce regurgitation, rumination, and ruminal motility (Buxton and Mertens, 1995). This fiber maintains a healthy rumen for the growth of microbes. Providing a suitable habitat for these microorganisms, the ruminant is able to use the end products of microbial fermentation and biosynthetic activities (primarily volatile fatty acids) to meet its own nutritional needs (Yokoyama and Johnson, 1988). This symbiotic relationship between ruminants and their microbiota has been described as a classical example of the cooperative model in an animal-microbe relationship (Hungate, 1984; Yokoyama and Johnson, 1988). Even high quality forages must have enough cell wall material for rumen health and maintenance of the microflora. Insufficient amounts of digestible carbohydrates in rations may depress microbial growth and digestion of feed in the rumen, while excess digestible carbohydrates in rations can cause acidosis and/or low milk fat tests. A careful balance between digestible carbohydrate and cell wall content must be maintained for optimum production diets (Schingoethe, 1988).

Though fertilization increases yield and protein content, heavily fertilized grasses may contain low levels of digestible carbohydrates, particularly with higher rates of nitrogen fertilization (Kunelius and Suzuki, 1978). Nitrogen fertilization does not necessarily improve the digestibility of grasses on a percentage basis because increased nitrogen compounds are compensated for by a reduction in digestible carbohydrates and an increase in lignification often due to increased growth rates (Van Soest et al., 1978). However, the yield response to nitrogen fertilizer of forage grasses can increase carbohydrates on a per area basis, especially when harvest management practices are optimized (Casler, 2005; Malhi et al. 2002).

The ability of forages to grow in situations unsuited to other crops or in conjunction with other crops makes them valuable and versatile for producers (Klebesadel, 1983). However, because of their ability to grow in marginal areas, managers often grow forages on poorer land and seldom manage them as well as they do their more readily marketable cash crops (Follett and Wilkenson, 1995). Several studies have shown substantial economic benefit from forages under proper management indicating the need for nutrient management strategies of forage crops (Zentner et al., 1989; Duffy and Smith, 2000).

The main influences on forage quality of cool season grasses are the environment and management schemes. Of the environmental factors, temperature has a greater effect on forage quality compared to water deficits, light intensity, and nutrient availability (Horrocks and Vallentine, 1999). Baker and Jung (1968) suggested optimum day temperature for smooth bromegrass to be between 18 and 25° C. Night temperature may be the most important factor limiting carbohydrate reserves, with reserves decreasing as night temperature increases (Baker and Jung, 1968). At temperatures below the optimum for growth, soluble sugars can accumulate because photosynthetic rate is less sensitive to low temperature than is growth and respiration. This may be why cell components in plants grown in warm environments are usually less digestible than in plants grown in cooler environments. Forages produced at locations with cool temperatures, such as those at high latitudes or elevations, tend to be of higher quality than forages produced in warmer climates because the have more digestible cell-walls and greater sugar accumulation (Buxton and Mertens, 1995).

A study by Heide and Hay (1985) compared smooth bromegrass varieties common to northern latitudes grown under short days (8 hour light) and long days (continuous light). The group exposed to continuous light showed large and significant increases in dry weight, height, and leaf area compared to the group grown under 8-hour days, at essentially identical daily inputs of radiant energy (Heide and Hay, 1985). The study also found a pronounced interaction between temperature and day length such that the greatest photoperiodic stimulation occurred at lower growing temperatures (< 15 C), suggesting that these grasses are well adapted to the cool, high-altitude summer. In a later study by Hay and Pedersen (1986) high altitude grasses grew more slowly by delaying floral initiation and, consequently, indicating early season peak in grass growth may persist longer. The delay of floral initiation maintained the grasses in a vegetative stage with higher forage quality than grasses reaching floral initiation.

Other studies by Cooper (1964) and Ostgard and Eagles (1971) have indicated that the main advantage of high latitude varieties is in their appropriate response to environmental cues such as cold, freezing stresses, and shorter days signaling the onset of winter that make these varieties more persistent in northern latitudes.

Another environmental factor, water stress, typically slows development of forages Halim et al. (1989). When leaf loss associated with drought is not severe, water deficit may actually improve forage quality (Peterson et al., 1992; Shaeffer et al., 1992). Also, greater light intensity tends to increase soluble carbohydrate content and digestibility of grasses while increasing temperature favors the conversion of photosynthetic products into structural matter (cell wall) (Deinum and Van Soest, 1968).

The three primary management tools producers use to manage the quality of their forages are defoliation regime, stage of maturity at harvest, and fertilization practices. Observations on the growth and persistence of grasses in the United States and elsewhere have led to the belief that perennial grasses undergo cyclic periods of utilization and storage of reserves that are closely associated with growth stage and frequency of harvest (Jung et al., 1974). In the fall and after each cut, if the latter does not kill the plant, the accumulation of reserve substances permits re-growth, followed eventually by development up to flowering and the formation of seeds (Voisin, 1959). Matching growth stage and frequency of harvest with nutritive quality and yield is a careful balance for the producer. The producer must maintain the sustainability of the grass stand for continued production, yet manage for nutritive quality and yield. An acceptable compromise for time of harvest of bromegrass at first cutting appears to be around the early head growth stage (Rohweder et al., 1978). Studies in Alaska have described optimum harvest time for bromegrass to be when the heads are emerged from the sheath and just coming into flower (Irwin, 1945). Many grasses, including smooth bromegrass, do not produce a second set of reproductive parts once they have been harvested. Stands harvested at earlier growth stages or frequently harvested should be left to grow without grazing or cutting in mid-summer and fall to ensure complete recovery (Wright et al., 1967; Jung et al., 1974). Generally speaking, factors that slow plant maturity will maintain forage quality for a longer time (Van Soest et al., 1978). Numerous researchers have documented the decline in nutritive value of forages with increasing age (Van Soest et al., 1978; Wright et al., 1967). Proper fertilization, improved soil fertility management practices, and harvesting at earlier growth stages improve forage quality, yet harvesting too early may reduce yields (Follett and Wilkenson, 1995; Kunelius and Suzuki, 1978).

When producers understand the cyclical pattern of their forage crop they can produce good quality forage and sustain more productive stands of grasses.

Nitrogen is an important nutrient and a major limiting factor affecting the growth and productivity of forage grasses (Leyshon and Campbell, 1995). In contrast to other plant nutrients used for fertilizer, N has relatively little carryover and is most effective when applied on a crop-by-crop basis, shortly before the period of most rapid growth and greatest demand by the crop (Olson and Kurtz, 1982; Zentner et al., 1989). Fertilizer management strategies available to growers include type and rate of fertilizer, time of application, and method of application (Welch, 1984). Numerous studies have confirmed that fertilization with nitrogen increases forage yield and crude protein (Leyshon, 1991; Wright et al., 1967; Olson, 1984). Northern perennial grasslands often are nitrogen deficient and respond to nitrogen fertilization (Black and Wright, 1979; Power, 1981), yet producers may have limited information on forage response to fertilization (Ukrainetz et al., 1988).

Early studies in Alaska found that broadcasting from 150 to 400 pounds of commercial nitrate fertilizer on grasses can more than double the yield of hay or pasture (Irwin, 1945). Later studies comparing different commercial nitrate fertilizers found similar results. Laughlin (1962) found the most economical rate of nitrogen to be 200 pounds per acre, spring applications superior to fall applications, and split applications improving second cutting yields, but not total season yields.

Efficient use of nitrogen fertilizer is essential for optimum yields, good quality, and the best economic benefit to the producer. The traditional approach for measuring percent recovery of applied nitrogen is by annual nitrogen recovery (ANR) in which nitrogen recovery in unfertilized plots is subtracted from total nitrogen recovery in fertilized plots divided by the quantity of applied N. Percent N fertilizer recovery in the aboveground plant parts is probably the most commonly used definition of agronomic nitrogen use efficiency (NUE) (Bock, 1985). Leaching, denitrification, immobilization, and NH_3 volatilization are the processes known to be of practical significance in lowering availability of N to plants (Bock, 1985). Laughlin et al. (1976), measured nitrogen uptake at two different nitrogen fertilization rates and showed the higher rate significantly increases nitrogen uptake, but percentage uptake is greater at the lower rate. A study of smooth bromegrass in Alaska with single and split applications showed single nitrogen applications generally resulting in higher nitrogen uptake for the first cutting; the opposite was true for the second cutting (Laughlin, 1978). Recently in Alaska, Zhang et al. (2006) showed average NUE of 26-30% for smooth bromegrass fertilized with urea, lower than reports of 44% by Zemenchick and Albrecht (2002). However, liquid manure applications for the Alaskan study showed average NUE values were 45%, closer to previous reports of 44%.

The forms of N fertilizer most commonly used on forage crops are urea, ammonium sulfate, and ammonium nitrate (Stangel, 1984). Urea has replaced ammonium nitrate as the major N fertilizer product produced and consumed in the world today (Stangel, 1984).

Studies have shown both of these sources to be equivalent nitrogen sources for the primary growth of forage, though urea was less efficient in secondary growth under summer conditions (Kunelius et al., 1987). This may be due to increasing air temperatures and dry conditions associated with nitrogen losses from urea through volatilization (Kunelius et al., 1987). Nitrogen recovery of urea may be improved if rainfall is received immediately after surface application (Malhi et al., 1995). Overall, the high analysis, ease of application, lack of specialized equipment needed, and associated savings in transportation costs make urea a very attractive choice of N fertilizer, especially in regions with natural gas supplies (Russelle, 1992), such as Alaska, where a large urea plant is currently in operation.

As nitrogen usage on grasslands increases, possible pollution of ground water with nitrate attributable to increased nitrogen fertilization becomes more of a concern. To address nitrate pollution issues, many states have enacted best management practice (BMP) guidelines for agriculture (Guillard et al., 1995; Stevens et al., 2005). Measurements such as agronomic NUE are important from an environmental perspective, since nitrogen that is not recovered by crops can be lost from soil-plant systems and can adversely affect the environment (Bock, 1985). These measurements are valuable monitors from a producer's efficiency position, as well as for the development of best management practices. Investigators have shown that movement and accumulation of nitrogen may be negligible when nitrogen fertilizer applications are appropriately used according to soil and environmental conditions (Leyshon, 1991; Herron et al., 1968;

Ogus and Fox, 1970). Others have shown that timing fertilization to physiological growth needs may influence NUE (Singer and Moore, 2003). Larson et al. (1971) and Malhi et al. (1991) found that at high nitrogen rates, nitrogen fertilization on fine-textured soils under northern climatic conditions did not result in significant movement and accumulation of NO_3-N in the ground water under smooth bromegrass.

Materials and Methods

Plots were established on four smooth bromegrass fields in Alaska. All field sites were located on farmers' fields that had been in production for at least 10 years. Plots were located near Delta Junction at Tanana Loop (64°00N, 145°44'W) and Sawmill Creek (63°58'N, 145°06'W), at Fairbanks (64°52'N, 147°52'W), and at the University of Alaska Matanuska Experiment Farm (61°06'N, 149°50'W) near Palmer. Treatments consisted of 2 rates of fertilizer N applied at different times (Table 1). Plots were 3.04 m^2 in size and were laid out in a randomized complete block design with four replicates. The same plot plan was used at all locations.

Triple super phosphate and potassium in the form of K_2SO_4 were uniformly broadcast across all plots at a rate of 250 kg ha $^{-1}$ to give 48 kg P ha $^{-1}$ (112 kg P_2O_5 ha $^{-1}$) and 92 kg K ha $^{-1}$ (112 kg K_20 ha $^{-1}$). Nine urea nitrogen fertilization treatments were applied at different rates over the growing season (Table 1). Six treatments resulted in a total application of 140 kg ha^{-1}, two resulted in 252 kg ha^{-1}, and one treatment received no N over the growing season.

Plots were harvested twice per growing season at early head for the first cutting (Rohweder et al., 1978). A 1 m^2 square area was cut by hand from each plot at a height of 4 cm. Non-crop plant material (weed) was separated from grass samples. Stem and leaf separations were done on two replications to determine the proportion of each. Stage of maturity for first cut was determined by counting the % of plants in head of one replication (Rohweder et al., 1978). The early head stage of growth was visually estimated by observing plot biomass and traditional harvest times for second cuts. After plots were sampled, sites were mowed with a flail mower or a sickle bar mower followed by N fertilizer treatment applied by hand .

All samples were dried at 60°C for 48 hours prior to grinding through a 2mm mesh screen. Sub-samples of grass were ground to pass a 20-mesh screen. Ground sample was stored in plastic bottles and placed in a 120-L plastic drum and tumbled at 15 rpm for 20 minutes to thoroughly mix the samples before near infrared reflectance spectroscopy (NIRS) spectra were collected with either a Pacific Scientific (Silver Springs, MD) Model 6250 or NIRSystems (Silver Springs, MD) Model 6500 NIR scanning monochrometer. Near infrared reflectance spectroscopy and Infrasoft Software International (ISI) software was used to analyze for crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) (Van Soest and Pidgen, 1980). Equations for NIRS were developed using wet chemistry results from the calibration set of randomly chosen samples. The Infrasoft International (ISI) program Calibrate was used for all equations (Shenk and Westerhaus, 1991). Apparent nitrogen recovery (ANR) = [(kg N recovered at N_x – kg N recovered at N_o)/N applied at N_x] x 100, and nitrogen use efficiency (NUE) = [(kg DM produced at N_x – kg DM produced at N_o)/ N applied at N_x) x 100 were calculated from yield measurements (Zemenchik and Albrecht, 2002).

Data were analyzed by analysis of variance following a randomized complete block design (Gomez and Gomez, 1984). The statistical program, Statistix 8.0, (Analytical Software, Inc.) was used for analysis of variance and when significant main effects were found ($p<0.05$) Tukey's Honestly Significant Difference (HSD) was calculated from the Standard Error Mean (SEM) and the upper 5% points of the studentized range (Q) for means separation (Petersen, 1994).

Results and Discussion

This study demonstrated results consistent with others that showed grass production responds markedly to nitrogen (N) application (Malhi et al., 2002; Hopkins, 2000; Follett and Wilkenson, 1995). Temperature and precipitation for the study sites in 1999 and 2000 are shown in Tables 2 and 3. Soil properties for the four sites are shown in Table 4. The sites used in this study represent typical Alaskan, established stands of smooth bromegrass forage in current use.

Dairy farmers have capitalized on the forage response to N to increase their output and productivity per unit area and/or to reduce production costs. As well as increasing dry matter yield, this response to N can provide more flexibility in management through the reduction of seasonal variability in grass growth or the ability to better predict productivity (Jarvis, 1998). Alaskan producers have a unique situation where efficient use of N fertilizer is important to increase dry matter yields and forage quality due to a shorter growing season than other livestock production areas and because many high quality (high in crude protein and energy) are not locally produced. This study was designed to provide information to Alaskan dairy producers on increasing dry matter yields and forage quality.

This forage showed typical dry matter yield responses to increased N fertilization: most treatments where N fertilizer was applied showed significantly higher dry matter yields than the control treatment where no N was applied ($p < 0.05$). These results are consistent with other studies on N fertilization of grass (George et al., 1973; Hanson et al., 1983; Malzer and Schoper, 1984; Laughlin, 1987). Sawmill Creek was the only site where forage yield in the control was not significantly lower than N treatments when yields were averaged over the entire two-year study ($p<0.05$).

High N fertilizer treatments (High Spring, High 60/40) generally increased dry matter yields over lower N treatments (Tables 5-8) but this statement cannot be statistically supported across sites for the entire study: at Palmer both High N treatments were significantly ($p < 0.05$) higher than low N treatments in year 2000 when yields were averaged over both cuts (Table 6); at Fairbanks the High Spring treatment was significantly ($p < 0.05$) greater than other treatments except the 50/30/20 treatment when averaged over both cuts in year 2000 (Table 5); and at Tanana Loop when yields were averaged over the two cuts in 1999, High N treatments were significantly ($p < 0.05$) greater than other treatments.

Split N treatments were designed to time N fertilization with crop growth needs. Significant differences ($p < 0.05$) among split treatments were not apparent, consistent with (Laughlin, 1978; Hanson et al., 1983; Malzer and Schoper, 1984). As opposed to a higher yielding first than second cut for single N applications, split treatments appeared to produce first and second cuts of similar yield (Tables 5-8), but this was not tested statistically. Other studies have shown improved dry matter yields with split treatments, but indicate that these increases may not be economical (Krueger and Scholl, 1979). Sweetman and Brundage (1960) recommended spring and early summer fertilization for Alaska, and, with irrigation, even a third fertilization treatment late in the summer. These treatments recommended by Sweetman and Brundage (1960) provided the grass crop with a more consistent N supply over the growing season versus the one-time applications, but economic implications were not mentioned. It is not known if the returns on the split treatments are worth the time and economic costs of additional fertilizer applications. Two important efficiency factors that play into this theme, nitrogen use efficiency (NUE) and apparent nitrogen recovery (ANR) will be discussed later in this section.

Yields among sites may have differed due to environmental conditions such as temperature and precipitation (Tables 2 and 3). The Sawmill Creek smooth bromegrass site appeared to have a less dense stand (low tiller density) and smaller plants. When harvesting, soils appeared drier than other sites though precipitation was similar. These field observations were recorded because it was the only site that did not experience lodging of the grass. Where lodging occurred, moisture seemed to be trapped at the soil surface. Sawmill Creek may not have retained moisture as well as other plots and, additionally, the N fertilizer may have volatilized at the surface due to lower tiller density and dry conditions rather than moving into the soil where roots could reach it.

A factor possibly affecting yields at Tanana Loop were late second cuttings in 1999 that may have facilitated winterkill. When plots were harvested at these two sites for the first cut of 2000, I noted plots had experienced winterkill, but grass surrounding the plots harvested at the late 1999 cutting date were not affected. Annual yields at both the Sawmill Creek and Tanana Loop sites were significantly lower ($p < 0.05$) in 2000 than

1999 for all N treatments. This effect was especially pronounced at Tanana Loop where 2000 yields were often more than 2240 kg ha^{-1} less than 1999 yields. Low yields (less than 1300 kg ha^{-1}) were harvested at Tanana Loop after the winter of 1999-2000 (Table 7). Others have noted this occurrence, and recommended stands harvested at earlier growth stages or frequently harvested should be left to grow without grazing or cutting in mid-summer and fall to ensure complete recovery (Wright et al., 1967; Jung et al., 1974). Treatment effects such as differences between high and low N fertilizer application levels and split rates may have been masked in smooth bromegrass at Tanana Loop because of year and cut differences due to winterkill.

The grass stage of development at harvest may have influenced yield and quality among sites over the 1999 and 2000 seasons at Fairbanks and Palmer. Second cuts were almost two weeks earlier in 2000 than 1999, thus, the reduction in yield may be related to an earlier harvest date (Wright et al., 1967). The stage of development refers to the maturity of the forage (Horrocks and Vallentine, 1999). The less mature the crop, the less the dry-matter-yield and the higher the quality (i.e., low cell wall content and high protein). Striking a balancing between forage yield and quality is dictated by the nutritional needs of the animal and is most effected by stage of development (i.e., time of harvest).

Of all forage quality measurements, crude protein (CP) is usually the most common and directly affected by N fertilization (McCaughey and Simons, 1998). Increases in CP follow an increase in N fertilizer application (Malzer and Schoper, 1984). The results of this study support this principle. High N fertilizer treatments were usually associated with greater CP percentages (Tables 5-8). Midseason, and often split, N treatments generally showed high second cut CP percentages relative to other treatments.

Crude protein levels in this study compared favorably with reported CP values from more temperate regions in the U.S. (Horrocks and Vallentine, 1999) and other Alaskan studies (Sweetman and Brundage, 1960), indicating potential for high protein and quality forages in Alaska. Horrocks and Vallentine (1999) reported average CP for smooth bromegrass was 16 percent for early vegetative stage of maturity and 10 percent for late bloom stage of maturity in the conterminous United States. Many of the Alaskan sites in this study showed N treatments with levels of CP at 16 or higher when they were harvested in the late vegetative stage of second cuts. High CP values were found for smooth bromegrass at Sawmill Creek, perhaps because grass stands were less mature, dense, and produced lower yields than at other sites. The winterkill between the 1999 and 2000 seasons may also have affected CP in smooth bromegrass at Tanana Loop. Annual CP was significantly higher ($p < 0.05$) in 2000 than in 1999 (Table 7). Within the 2000 season at Tanana Loop, first cuts were higher in protein than second cuts, possibly indicating a less mature grass recovering from winterkill with more leaf material as compared to stem. Immature grasses have greater leaf percentages and therefore contain more CP (Scheaffer et al., 1998).

Crude protein levels for the midseason N fertilizer application in most second cuts were significantly higher ($p < 0.05$) than other low N treatments but not always significantly higher than the high N treatments. The second year at the Fairbanks (Table 5) and Sawmill Creek site (Table 8) were the only times the midseason treatment was not significantly higher ($p < 0.05$) than other low N treatments. These sites showed the midseason N application close to high N application values. One explanation for these high CP values associated with the midseason N treatment may be that the timing of the midsummer treatment matched grass growth needs. Other studies (Malhi et al., 1986) found late spring (midseason treatment) versus early spring N fertilization treatment translates into increased protein content, but not forage yield. Both these explanations may be feasible as the midseason N treated plots were not relatively high yielding which might indicate a less mature grass, though first cut head to stem ratios were consistent among treatments. The midseason single application N fertilization treatment usually showed significantly higher ($p < 0.05$) CP levels for second cuts than the single spring and split low N fertilizer applications for both the 1999 and 2000 seasons at most sites. An exception was Tanana Loop, where CP percentages for the first cut in 2000 were very high – at least 15 % for all treatments (Table 7). This may be a consequence of low yields due to winterkill from the previous year. Without considering the first cut of 2000, the CP pattern at Tanana Loop follows other sites. My results indicate that delaying fertilization for a period of time to late spring (such as two to three weeks closer to the midsummer timing) may increase CP in the forage crop. These results may indicate a need for testing other split applications where the timing of second fertilization is closer to midsummer, rather than immediately after the first cut. Though the midseason treatment had very high CP values for second cuts, first cuts ranked among the lowest CP values for treatments because they were essentially the same as the control (no N treatment). Though midseason treatment CP results were high, lower yields may not be an acceptable trade-off for midseason high CP second cut grass unless there is a demand for high protein hay.

The study showed many treatments with CP levels between 15 to 20 percent - favorable values that would put grasses in the top three grades (out of six) for CP values according to the Hay and Marketing Task Force (Horrocks and Vallentine, 1999). Where more N fertilizer was applied, higher CP values resulted, but this study shows that timing may also be a factor. Though split applications did not significantly increase CP percentages, delaying fertilization until midsummer had an effect on second cut CP percentages.

Measurements of neutral detergent fiber (NDF) and acid detergent fiber (ADF) represent an important quality predictor because they estimate the digestibility (ADF) and the rate of passage (NDF) of the forage through the animal. It has been shown that these fiber measurements are of greater benefit than CP in predicting forage quality because they do not show variation to environmental conditions as CP does (Horrocks and Vallentine, 1999). As both measurements represent cell wall constituents, they are well correlated as shown in Tables 5 through 8.

Significant differences among treatments were not as apparent for fiber as they were for yield and CP values. Stage of maturity has the largest influence on fiber values

(Scheaffer, 1998), and since a goal of this study was to harvest grasses at similar maturities across treatments variability was predicted to be small. As grasses mature, fiber content increases and digestibility decreases (Wright et al., 1967; Cherney et al., 1993). The significantly lower ($p < 0.05$) fiber values for the no nitrogen and midseason treatments at most sites may indicate that grass harvested in these treatments was less mature than grass harvested from other treatments. Lower yields and higher CP in the midseason and control treated plots at all sites also support the claim that these treatments may have delayed maturity compared to other treatments.

All NDF and ADF percentages were comparable and often optimum when compared to other forages. Fiber values ranked in the two highest grades (out of six) according to the Hay and Marketing Task Force (Horrocks and Vallenine, 1999). This might be because forage quality has been found to be best in cool weather (Deinum et al., 1981) and the comparatively cooler Alaskan summers relative to other agricultural regions may slow the formation of cell wall fiber (ADF and NDF). Over this two year study, all sites ranged from 50 to 55 percent NDF with little variation except Sawmill Creek where percentages were 48 to 49 percent NDF. Acid detergent fiber values also varied little at each site over the 1999 and 2000 harvests: all sites averaged under 30 percent ADF. Fiber variation among treatments was low and differences were not significant. Variation typically only occurred between harvests and cuts, and even then, it was small.

Although yield is usually the main factor influencing a producer's fertilizer management choices, from an environmental and economic standpoint yield should not be the only important factor due to potential for nitrate accumulation and inefficient use of N fertilizer (Guillard et al., 1995; Stevens et al., 2005). Nitrogen use efficiency (NUE) determines the percent fertilizer recovery in the aboveground plant parts. Nitrogen recovery can be influenced by species, growth habit, N application rate, precipitation, soil type, and root system (larger and more vigorous root systems in fertilized plots usually recover more N from the soil, excluding that added as fertilizer, than does the unfertilized crop) (Zemenchik and Albrecht, 2002; Guillard et al., 1995; Bock, 1985). Nitrogen fertilization has also been shown to increase root mass in bromegrass (Malhi and Gill, 2002).

When NUE treatment values were averaged over 1999 and 2000, the midseason treatment consistently ranked lowest among treatments although it was not significantly lower ($p < 0.05$) than low split N treatments. Though not significant, NUE appeared to decrease as N fertilization rates increased, and split treatments were associated with higher NUE values. This observation was consistent with results found in other studies (Zemenchik and Albrecht, 2002; McCaughey and Simons, 1998). Split treatments may improve fertilizer efficiency, reducing the potential for nitrate accumulation and subsequent leaching but significant effects were not apparent for this study. The only significant effects for NUE in this study were years ($p < 0.05$). First year NUE values were lower than second year values. This may have to do with the availability of N to the plant as more N may have been present in the soil in second years or the root mass may have increased year to year (Malhi and Gill, 2002). This study showed average NUE percentages similar to other Alaskan studies. Zhang et al. (2006) reported average NUE ranged from 26 to 30%, similar to percentages for this study. High application rates decreased NUE percentages at all sites, but no significant differences ($p < 0.05$) were found (Table 9).

Another measurement important to producers when making fertilization choices is apparent nitrogen recovery (ANR). Differences between high and low treatments as well as single and split applications were not as apparent as differences between the 1999 and 2000 seasons across sites (Tables 5-8). As with NUE, the only significant differences were found between years ($p < 0.05$). Tanana Loop and Sawmill Creek had higher ANR values in 1999 than 2000 in contrast to Fairbanks and Palmer sites where 2000 ANR values were usually higher than 1999 values. As with NUE the midseason treatment ranked consistently lower than other treatments across sites probably due to the late application of N fertilizer but this was not a significant effect at any site. It is thought that split treatments may outperform single treatments regardless of high or low N fertilizer rate, but this study did not show significant differences between split and single high or low treatments. Apparent nitrogen recovery for Fairbanks and Tanana Loop showed low split N fertilizer treatments approaching 60 percent. At Tanana Loop, ANR values for the 50/30/20 split in the first year were near 70 percent. The high ANR values in this study are higher than other bromegrass studies where high ANR values were around 50 percent (George et al., 1973; Zemenchik and Albrecht, 2002). Zemenchik and Albrecht (2002) and Singer and Moore (2003) found ANR values were inversely related to the amount of N applied, but our study was not able to discern this trend at any of our four sites in Alaska.

Nitrogen use efficiency and apparent nitrogen recovery are important measurements to producers because of the economic and environmental information they may provide to producers. Nitrogen use efficiency and ANR measure efficiency that indicates a fertilizer is meeting the requirements of a forage without excess waste to the environment. These measurements in conjunction with traditional yield, crude protein, and fiber values for bromegrass illustrate the trade-offs producers must weigh when making N fertilizer plans for high quality forage crops. Though split and single N fertilizer applications did not significantly differ in dry matter yields or CP, split applications in this study usually had higher nitrogen use efficiency and apparent nitrogen recovery values. The more efficient use of fertilizer by the crop in the split applications could be an incentive for the producer to use these treatments over single applications because of the consequent economic and environmental impacts of excess fertilizer run-off. Splitting N applications normally improves forage production and its distribution in the growing season; however, the savings and workload distribution from the extra cost of split applications should be taken into consideration to arrive at the appropriate N management practice for smooth bromegrass (Malhi and Gill, 2002).

The 60/40, 50/50, and 33/33/33 split treatments showed highest NUE values, although they were not significantly different from other fertilizer treatments in this study. Though single and split high N fertilization treatments significantly increased ($p < 0.05$) dry matter yield and crude protein over both single and split low N fertilizer applications in many cases (consistent with the literature), the increases in these measurements may not outweigh the lower efficiency measurements when determining the best long-term N fertilizer plan.

Dry matter yield, quality, and efficiency values should be considered when choosing the best N fertilizer management scheme, but some measurements may be more indicative than others. Dry matter yield, CP, and N efficiency measurements are more effective when evaluating N fertilizer schemes than fiber measurements which are better managed by timing of harvest. This study showed potential for the production of high yielding, good quality grass forages in Alaska from a variety of N fertilizer applications.

Table 1: Nitrogen fertilizer treatments applied to smooth bromegrass in 1999 and 2000 at four sites in Alaska.

Treatments	Spring	1^{st} cut	Midseason	2^{nd} cut	Total	Total
	%	%	%	%	kg ha $^{-1}$	lbs/ac^{-1}
Spring	100	0	0	0	140	125
Midseason	0	0	100	0	140	125
60/40	60	40	0	0	140	125
50/50	50	50	0	0	140	125
33/33/33	33	33	0	33	140	125
50/30/20	50	30	0	20	140	125
High Spring	100	0	0	0	252	225
High 60/40	60	40	0	0	252	225
Control	0	0	0	0	0	0

Table 2: Monthly average growing season temperatures (°C) in 1999 and 2000 at four sites in Alaska.

Site	Year	May	June	July	August	September
Fairbanks	1999	5.9	15.4	14.8	13.5	6.1
	2000	7.9	16.4	15.3	11.1	5.8
Palmer	1999	7.9	13.6	14.6	13.7	9.4
	2000	7.9	13.2	14.2	12.3	7.7
Tanana Loop	1999	6.2	14.5	14.7	13.3	6.1
	2000	5.5	14.7	13.9	9.0	4.0
Sawmill Creek	1999	5.6	14.4	15.2	13.2	6.3
	2000	5.2	14.7	13.9	9.1	4.4

Table 3: Monthly average growing season precipitation (mm) in 1999 and 2000 at four sites in Alaska.

Site	Year	May	June	July	August	September	Total
Fairbanks	1999	5	13	11	10	10	48
	2000	10	7	9	28	13	67
Palmer	1999	8	7	11	21	11	58
	2000	5	6	11	11	16	49
Tanana Loop	1999	8	12	20	18	6	64
	2000	15	3	8	30	11	68
Sawmill Creek	1999	6	10	13	15	7	51
	2000	15	4	7	31	9	65

Table 4: Soil properties at four sites in Alaska.

Site	Soil Type	Soil Texture	Classification
Fairbanks	Fairbanks Silt Loam	Silt Loam	Typic Eutrocryepts
Palmer	Knik Silt Loam	Silt Loam	Typic Eutrocryepts
Tanana Loop	Tanana Silt Loam	Silt Loam	Typic Aquiturbels
Sawmill Creek	Volkmar Silt Loam	Silt Loam	Aquic Haptocryepts

(Natural Resources Conservation Service, 2007)

Table 5: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Fairbanks, Alaska in 1999 and 2000.

Treatment	Yield (kg/ha)	CP %	NDF %	ADF %
	Cut 1, 1999			
Spring	1230.2	13.8	53.2	27.8
Midseason	1020.1	10.0	52.1	27.5
60/40	1456.5	14.2	51.3	26.8
50/50	840.7	11.8	52.8	27.7
33/33/33	1807.3	12.0	53.1	28.0
50/30/20	929.0	13.3	53.4	28.1
High Spring	2442.6	14.4	53.7	28.2
High 60/40	2027.0	13.9	52.8	27.7
Control	1193.8	10.2	54.3	28.9
HSD(trtXcutXyr)	2974.3	5.7	4.3	2.9
SEM(trtXcutXyr)	521.8	1.0	0.8	0.5
	Cut 2, 1999			
Spring	2592.2	9.1	54.1	29.7
Midseason	1672.9	19.3	50.6	26.9
60/40	3872.2	11.3	55.6	30.7
50/50	3251.9	13.5	55.0	30.2
33/33/33	3810.7	10.2	55.0	30.4
50/30/20	3591.6	11.9	54.1	29.7
H Spring	3992.3	12.4	54.5	30.0
H 60/40	4084.2	14.6	53.9	29.2
Control	1318.1	8.5	52.2	28.2
HSD(trtXcutXyr)	2974.3	5.7	4.3	2.9
SEM(trtXcutXyr)	521.8	1.0	0.8	0.5
	Annual Total (yield) and Annual Means (%), 1999			
Spring	3822.4	11.4	53.6	28.8
Midseason	2693.0	14.7	51.4	27.2
60/40	5328.6	12.8	53.4	28.7
50/50	4092.6	12.6	53.9	28.9
33/33/33	5618.0	11.1	54.0	29.2
50/30/20	4520.7	12.6	53.8	28.9
H Spring	6434.9	13.4	54.1	29.1
H 60/40	6111.2	14.2	53.4	28.4
Control	2511.9	9.4	53.3	28.6
HSD(trtXyr)	2656.3	3.8	NS	NS
SEM(trtXyr)	488.3	0.7	0.6	0.4

Table 5: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Fairbanks, Alaska in 1999 and 2000, continued.

		Cut 1, 2000		
Spring	2539.2	12.9	57.65	31.45
Midseason	2644.4	9.6	60.3	33.4
60/40	3476.6	10.7	60.0	33.2
50/50	2627.6	10.5	59.5	32.9
33/33/33	3354.8	11.2	60.0	33.1
50/30/20	3606.9	11.6	58.9	32.6
H Spring	3979.6	13.8	59.9	32.7
H 60/40	3775.8	13.5	59.4	33.0
Control	1509.7	8.7	56.7	31.1
HSD(trtXcutXyr)	2974.3	5.7	4.3	2.9
SEM(trtXcutXyr)	521.8	1.0	0.8	0.5
		Cut 2, 2000		
Spring	1957.9	14.3	50.1	27.4
Midseason	2193.3	13.5	50.9	28.0
60/40	1861.4	15.2	50.3	27.0
50/50	1972.2	15.1	50.3	27.1
33/33/33	1544.5	13.1	50.5	27.4
50/30/20	2365.4	12.0	51.1	28.2
H Spring	2109.7	14.9	51.6	28.0
H 60/40	964.2	11.5	50.6	27.7
Control	2670.7	12.3	51.6	28.2
HSD(trtXcutXyr)	2974.3	5.7	4.3	2.9
SEM(trtXcutXyr)	521.8	1.0	0.8	0.5
		Annual Total (yield) and Annual Means (%), 1999		
Spring	4497.1	13.6	53.9	29.4
Midseason	4837.7	11.5	55.6	30.7
60/40	5338.0	12.9	55.1	30.1
50/50	4599.8	12.8	54.9	30.0
33/33/33	4899.3	12.1	55.3	30.2
50/30/20	5972.3	11.8	55.0	30.4
H Spring	6089.2	14.3	55.7	30.4
H 60/40	4739.9	12.5	55.3	30.3
Control	4180.4	10.5	54.1	29.8
HSD(trtXyr)	2656.3	3.8	NS	NS
SEM(trtXyr)	488.3	0.7	0.6	0.4

CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HSD, honestly significant difference; SEM, standard error mean; NS, not significant; trt, treatment; yr, year

Table 6: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Palmer, Alaska in 1999 and 2000.

Treatment	Yield (kg/ha)	Crude Protein %	NDF %	ADF %
		Cut 1, 1999		
Spring	2570.9	14.4	51.8	26.7
Midseason	2142.3	12.0	53.5	27.5
60/40	2556.2	14.2	50.3	25.9
50/50	2469.6	13.4	52.1	27.0
33/33/33	2415.0	12.2	51.3	26.7
50/30/20	2372.7	13.4	51.4	26.6
H Spring	2710.9	15.1	50.8	26.1
H 60/40	2482.3	15.0	51.0	26.2
Control	2212.8	11.5	51.6	26.9
HSD(trtXcutXyr)	1586.3	2.3	NS	NS
SEM(trtXcutXyr)	278.3	0.4	0.6	0.4
		Cut 2, 1999		
Spring	4084.8	13.3	55.6	29.9
Midseason	3684.1	17.7	53.9	28.4
60/40	3282.3	12.5	54.7	29.3
50/50	3433.2	12.3	56.0	30.2
33/33/33	2939.1	10.7	54.9	29.6
50/30/20	3020.5	12.3	54.8	29.3
H Spring	3798.5	17.0	54.5	28.6
H 60/40	3858.7	16.7	55.3	29.3
Control	1557.1	9.9	53.9	28.8
HSD(trtXcutXyr)	1586.3	2.3	NS	NS
SEM(trtXcutXyr)	278.3	0.4	0.6	0.4
		Annual Total (yield) and annual Means (%), 1999		
Spring	2944.3	13.8	53.7	28.3
Midseason	2781.0	14.8	53.7	27.9
60/40	2919.2	13.4	52.5	27.6
50/50	2964.9	12.9	54.0	28.6
33/33/33	2677.1	11.4	53.1	28.2
50/30/20	2696.6	12.8	53.1	27.9
H Spring	3254.7	16.1	52.6	27.4
H 60/40	3170.5	15.8	56.4	27.8
Control	1885.0	10.7	50.3	27.8
HSD(trtXyr)	897.0	NS	2.7	2.0
SEM(trtXyr)	164.9	0.3	0.5	0.4

Table 6: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Palmer, Alaska in 1999 and 2000, continued.

	Cut 1, 2000			
Spring	4084.8	12.5	55.62	28.52
Midseason	3684.1	8.7	53.3	28.6
60/40	4212.6	11.8	52.1	28.0
50/50	4046.3	10.7	53.8	29.0
33/33/33	4591.1	10.1	55.0	29.8
50/30/20	4966.4	10.6	55.5	30.3
H Spring	5229.2	13.5	55.2	29.8
H 60/40	5391.4	12.9	55.8	29.3
Control	2060.6	8.7	50.7	28.8
HSD(trtXcutXyr)	1586.3	2.3	NS	NS
SEM(trtXcutXyr)	278.26	0.4	0.6	0.4
	Cut 2, 2000			
Spring	1996.1	9.2	51.3	27.9
Midseason	1083.5	17.7	49.2	25.7
60/40	2931.8	10.8	53.7	29.5
50/50	3505.6	10.5	55.8	30.7
33/33/33	2659.5	9.0	54.2	29.8
50/30/20	2743.4	9.6	54.5	29.8
H Spring	4204.6	12.4	56.2	30.9
H 60/40	4167.7	13.2	57.0	31.3
Control	921.6	9.6	49.8	26.9
HSD(trtXcutXyr)	1586.3	2.3	NS	NS
SEM(trtXcutXyr)	278.26	0.41	0.6	0.4
	Annual Total (yield) and Annual Means (%), 2000			
Spring	3040.5	10.9	52.3	28.2
Midseason	2383.8	13.2	51.3	27.1
60/40	3572.2	11.3	52.9	28.8
50/50	3776.0	10.6	54.8	29.9
33/33/33	3625.3	9.5	54.6	29.8
50/30/20	3854.9	10.1	55.0	30.1
H Spring	4716.9	12.9	55.7	30.4
H 60/40	4779.5	13.0	56.4	30.8
Control	1491.1	9.2	50.3	26.8
HSD(trtXyr)	897.0	NS	2.7	2.0
SEM(trtXyr)	164.9	0.3	0.5	0.4

CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HSD, honestly significant difference; SEM, standard error mean; NS, not significant; trt, treatment; yr, year

Table 7: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Tanana Loop, Alaska in 1999 and 2000.

Treatment	Yield (kg/ha)	Crude Protein %	NDF %	ADF %
		Cut 1, 1999		
Spring	4910.4	16.3	56.0	29.9
Midseason	3118.5	10.1	56.5	30.7
60/40	4530.8	14.8	57.4	30.9
50/50	4594.9	14.1	56.5	30.5
33/33/33	4381.4	11.2	57.9	31.6
50/30/20	4809.4	12.4	57.1	31.0
H Spring	5362.9	17.9	55.6	29.3
H 60/40	5114.6	17.1	56.6	29.9
Control	3299.2	10.8	55.6	30.1
HSD(trtXcutXyr)	1755.0	4.6	NS	3.1
SEM(trtXcutXyr)	307.9	0.8	0.8	0.6
		Cut 2, 1999		
Spring	3616.0	9.7	54.0	29.7
Midseason	3549.7	16.4	51.3	27.5
60/40	4257.9	10.3	65.5	31.3
50/50	4372.9	10.5	55.7	31.5
33/33/33	3839.1	9.2	55.3	30.6
50/30/20	4818.8	9.9	56.2	31.1
H Spring	5058.7	11.6	56.2	31.4
H 60/40	5734.5	13.4	54.8	30.4
Control	2301.3	9.3	51.3	27.9
HSD(trtXcutXyr)	1755.0	4.6	NS	3.1
SEM(trtXcutXyr)	307.9	0.8	0.8	0.6
		Annual Total (yield) and Annual Means (%), 1999		
Spring	8526.0	13.0	55.0	29.9
Midseason	6668.0	13.2	53.9	29.1
60/40	8789.0	12.6	56.9	31.1
50/50	8968.0	12.3	56.6	31.0
33/33/33	8220.0	10.2	56.6	31.1
50/30/20	9628.0	11.1	56.6	31.1
H Spring	10422.0	14.8	55.9	30.4
H 60/40	10849.0	15.3	55.7	30.1
Control	1542.0	10.1	53.5	29.0
HSD(trtXyr)	3234.1	4.5	2.5	2.0
SEM(trtXyr)	594.5	0.82	0.5	0.4

Table 7: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Tanana Loop, Alaska in 1999 and 2000, continued.

		Cut 1, 2000		
Spring	1313.2	21.4	52.5	28.0
Midseason	933.3	18.3	50.3	26.5
60/40	1227.8	18.7	52.4	27.8
50/50	750.3	21.2	51.1	26.4
33/33/33	602.2	23.2	49.2	30.6
50/30/20	1172.4	17.4	52.5	28.2
H Spring	1106.7	20.3	53.4	28.6
H 60/40	827.8	20.5	52.8	28.1
Control	602.4	9.3	51.3	26.9
HSD(trtXcutXyr)	1755.0	4.6	NS	3.1
SEM(trtXcutXyr)	307.9	0.8	0.8	0.6
		Cut 2, 2000		
Spring	2174.3	11.0	51.6	28.4
Midseason	2258.0	17.1	48.9	26.6
60/40	3592.5	12.8	53.0	29.7
50/50	3344.8	13.5	51.6	28.7
33/33/33	2762.8	13.8	50.6	28.1
50/30/20	2173.4	11.3	50.6	28.1
H Spring	3826.4	14.5	52.8	29.7
H 60/40	2415.1	15.0	49.4	27.2
Control	939.9	11.1	48.5	26.6
HSD(trtXcutXyr)	1755.0	4.6	NS	3.1
SEM(trtXcutXyr)	307.9	0.8	0.8	0.6
		Annual Total (yield) and Annual Means (%), 2000		
Spring	3488.0	16.2	52.1	28.2
Midseason	3191.0	17.7	49.6	26.5
60/40	4820.0	15.8	52.7	28.7
50/50	4095.0	17.4	51.4	27.6
33/33/33	3365.0	18.5	49.9	26.9
50/30/20	3346.0	14.3	51.6	28.2
H Spring	4933.0	17.4	53.1	29.1
H 60/40	3243.0	17.7	51.1	27.6
Control	1542.0	13.0	49.3	26.8
HSD(trtXyr)	3234.1	4.5	2.5	2.0
SEM(trtXyr)	594.5	0.6	0.5	0.4

CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HSD, honestly significant difference; SEM, standard error mean; NS, not significant; trt, treatment; yr, year

Table 8: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Sawmill Creek, Alaska in 1999 and 2000.

Treatment	Yield (kg/ha)	Crude Protein %	NDF %	ADF %
	Cut 1, 1999			
Spring	1339.0	16.4	51.0	26.2
Midseason	1192.9	14.0	51.7	27.2
60/40	1676.7	16.4	52.1	27.0
50/50	1344.3	16.4	51.2	26.4
33/33/33	1443.6	13.3	51.5	27.0
50/30/20	1512.9	14.8	53.1	27.5
H Spring	1492.0	17.6	51.2	26.4
H 60/40	1413.1	16.9	52.1	26.9
Control	1534.9	11.0	52.8	27.9
HSD(trtXcutXyr)	1066.6	NS	3.3	2.4
SEM(trtXcutXyr)	187.12	0.8	0.6	0.4
	Cut 2, 1999			
Spring	2809.1	14.1	48.6	25.6
Midseason	1904.6	20.4	46.5	23.8
60/40	3142.3	16.2	50.2	26.5
50/50	2262.3	16.5	47.7	24.8
33/33/33	2089.7	13.2	47.9	25.4
50/30/20	2609.5	15.1	48.4	25.3
H Spring	3127.0	17.4	49.6	25.8
H 60/40	3093.9	18.5	49.1	25.2
Control	993.2	10.5	44.6	23.2
HSD(trtXcutXyr)	1066.6	NS	3.3	2.4
SEM(trtXcutXyr)	187.1	0.8	0.6	0.4
	Annual Total (yield) and Annual Means (%), 1999			
Spring	4148.2	15.3	49.8	25.9
Midseason	3097.6	17.2	49.1	25.5
60/40	4819.0	16.3	51.2	25.7
50/50	3606.6	16.4	49.4	25.6
33/33/33	3533.3	13.2	49.7	26.2
50/30/20	4122.4	14.9	50.8	26.4
H Spring	4619.0	17.5	50.4	26.1
H 60/40	4507.0	17.7	50.6	26.1
Control	2528.1	10.8	48.7	25.6
HSD(trtXyr)	1479.1	NS	NS	NS
SEM(trtXyr)	271.9	0.6	0.5	0.3

Table 8: Nitrogen fertilizer treatment effect on smooth bromegrass yield and quality at Sawmill Creek, Alaska in 1999 and 2000, continued.

		Cut 1, 2000		
Spring	1235.4	14.5	50.3	26.7
Midseason	1106.4	13.1	51.5	24.4
60/40	1231.1	14.6	50.0	26.4
50/50	1473.5	12.9	50.3	26.7
33/33/33	1704.2	13.5	49.8	26.6
50/30/20	1871.0	13.4	51.2	27.3
H Spring	1308.6	17.6	52.4	27.4
H 60/40	939.4	16.7	51.2	27.0
Control	802.3	10.4	50.4	27.0
HSD(trtXcutXyr)	1066.6	NS	3.3	2.4
SEM(trtXcutXyr)	187.1	0.8	0.6	0.4
		Cut 2, 2000		
Spring	955.5	17.3	44.6	23.1
Midseason	748.5	21.4	44.4	22.7
60/40	1177.3	17.7	45.4	23.7
50/50	1029.4	21.4	44.8	22.9
33/33/33	885.4	16.7	45.5	23.8
50/30/20	902.7	17.8	44.8	23.1
H Spring	1035.3	18.3	46.1	23.6
H 60/40	1104.9	19.6	45.1	23.0
Control	447.7	11.4	46.0	24.4
HSD(trtXcutXyr)	1066.6	NS	3.3	2.4
SEM(trtXcutXyr)	187.1	0.8	0.6	0.4
		Annual Total (yield) and Annual Means (%), 2000		
Spring	2190.9	15.9	47.4	24.9
Midseason	1854.9	17.3	47.9	25.1
60/40	2408.4	16.2	47.7	25.0
50/50	2503.0	17.2	47.5	24.8
33/33/33	2589.6	15.1	47.7	25.2
50/30/20	2773.7	15.6	48.0	25.2
H Spring	2343.9	17.9	49.2	25.5
H 60/40	2044.3	18.1	48.1	25.0
Control	1249.9	10.9	48.2	25.7
HSD(trtXyr)	1479.1	NS	NS	NS
SEM(trtXyr)	271.9	0.7	0.5	0.3

CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; HSD, honestly significant difference; SEM, standard error mean; NS, not significant; trt, treatment; yr, year

Table 9: Nitrogen fertilizer treatment effect on nitrogen use efficiency (NUE) and apparent nitrogen recovery (ANR) on smooth bromegrass at four sites in Alaska averaged over 1999 and 2000.

	Fairbanks		Palmer		Tanana Loop		Sawmill Creek	
	NUE	ANR	NUE	ANR	NUE	ANR	NUE	ANR
Treatment				%				
Spring	15.7	36.5	18.6	47.7	20.0	55.4	9.1	30.1
Midseason	1.8	34.1	15.1	39.6	13.0	45.1	5.0	25.1
60/40	24.2	49.9	25.3	61.8	22.6	58.4	14.0	45.0
50/50	18.7	41.8	24.0	50.5	20.4	52.0	8.3	33.5
33/33/33	29.9	60.0	23.7	42.3	20.5	41.4	10.1	30.3
50/30/20	27.4	57.4	24.1	49.7	23.4	46.8	12.5	38.6
H Spring	17.4	42.6	18.2	50.8	16.3	49.5	8.8	30.9
H 60/40	14.1	40.9	18.1	50.0	13.8	44.6	7.1	29.0
HSD	NS	NS	NS	NS	NS	NS	NS	NS
SEM	4.0	7.9	3.8	6.5	2.5	6.7	2.5	4.3

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